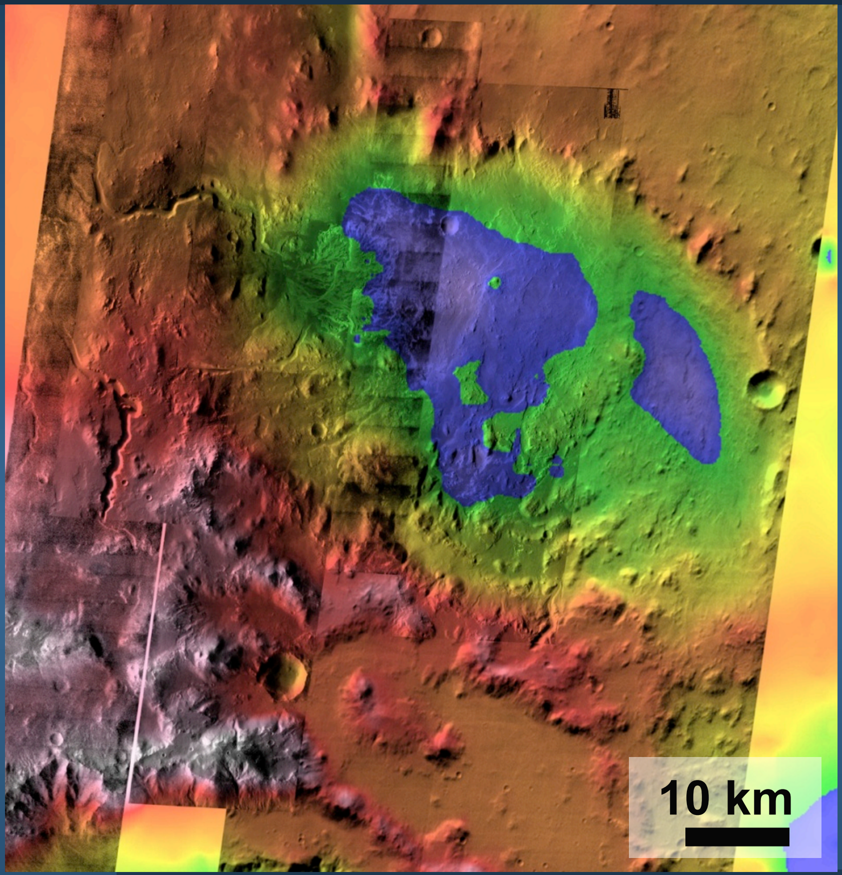
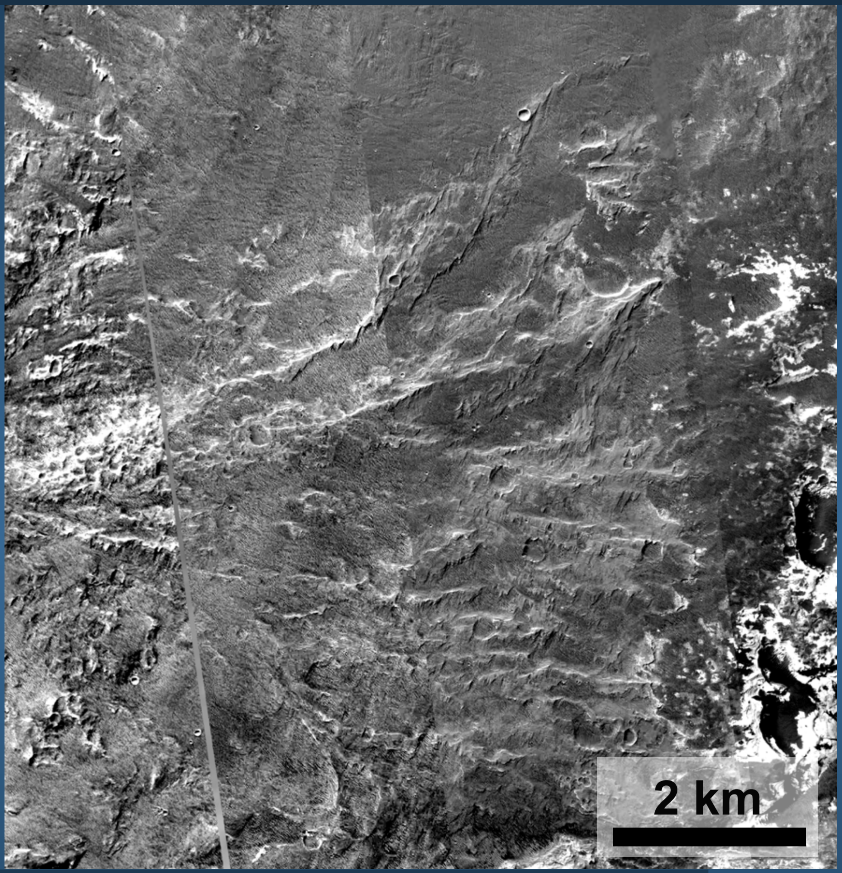
MSL Fluvial Processes Tiger Team

5th MSL Landing Site Workshop





Ross Irwin (presenting), Jim Bell, Bill Dietrich,
John Grant, John Grotzinger, Sanjeev Gupta,
Alan Howard, Edwin Kite, Nicolas Mangold,
Jeff Moore, David Vaniman, Kelin Whipple

Mandate

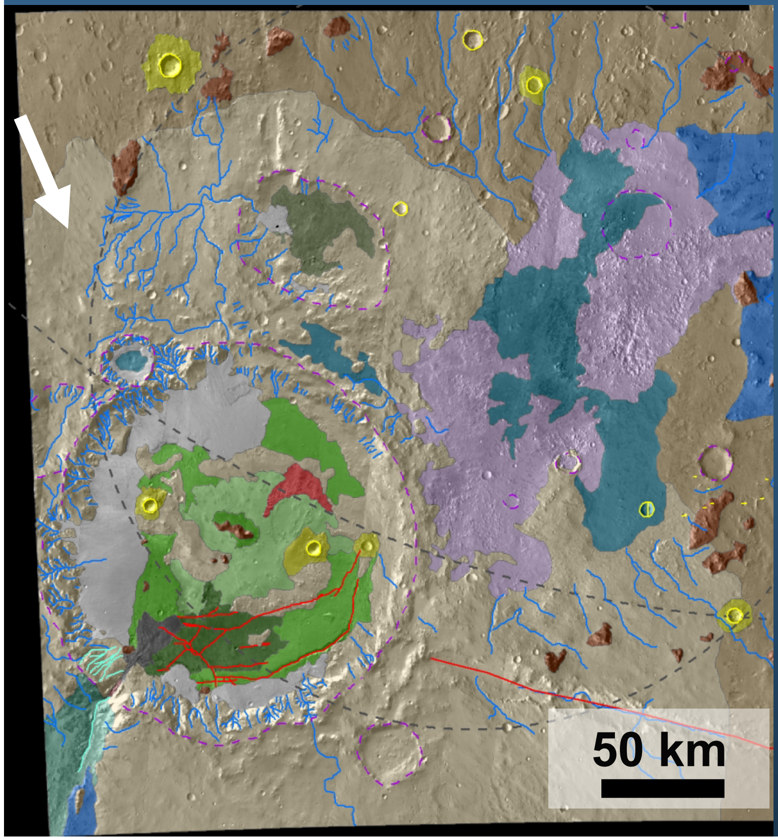
Charge: Perform calculations of discharge volumes, processes, and histories that could help to fine-tune hypotheses for fluvial activity at the sites; assess potential flow durations and discharge/catchment paths, as well as evidence for multiple events exploiting the same channel systems; assess potential role of precipitation vs. overland flow vs. subsurface flow at the sites

What was the hydrologic cycle like at this place on Mars: did it feature major fluxes involving groundwater or rainwater? What would be the observations we could make with the rover that would help distinguish between these scenarios? What sort of research plan could be devised to study various segments of the source-to-sink systems, including intermediate sediment reservoirs?

Elaborate a set of testable hypothesis that we could rank in terms of how likely it would be that we could do the test with our payload, and where the key targets to conduct the tests would be.

Age of Holden Crater

	Count	N(x)	+/-	Epoch	Range
N(1)	94	2001	206	LH	EH-LH
N(2)	32	681	120	LH	EH-LH
N(5)	6	128	52	EH	EH-LH



- Holden crater is Hesperian and post-dates Late Noachian valley networks. Gale crater may be roughly contemporary.
- Fluvial erosion of Holden and Eberswalde craters represents a later interval of fluvial activity. Local/regional/global scale is not yet well constrained.
- Other Hesperian valleys are recognized on Mars, including in the highlands, both near and far from contemporary craters.

Irwin and Grant, submitted, unit Hc

Eberswalde Crater Paleohydrology

Meander loops in Eberswalde crater

North South

Eberswalde Crater Paleohydrology

Eberswalde meander dimensions (m)

Paleo-channel	Width (mean of 5) W_b	Wavelength λ_m	Arc distance (mean of 3) λ_a	Belt width B	Radius of curvature (mean of 3) R_c
North	127	1240	785	890	250
South	54	740	530	420	170

Measured and expected channel width based on meander dimensions (m)

Paleo-channel	Measured width (mean of 5)	Width, from wavelength	Width, from arc distance	Width, from belt width	Width, from radius of curvature
North	127	96	87	114	97
South	54	61	61	58	69

$W_b = 0.17\lambda_m^{0.89}$ $W_b = 0.23\lambda_a^{0.89}$ $W_b = 0.27B^{0.89}$ $W_b = 0.71R_c^{0.89}$ (*Williams*, 1986)

Eberswalde Crater Paleohydrology

Width-wavelength relationships in two inverted paleochannels

- Consistent with terrestrial meandering rivers
- Inverted channels are not ideal for width measurements (deposit can be wider than channel or narrowed by erosion) but are well-preserved here

Dominant discharge for northern inverted channel

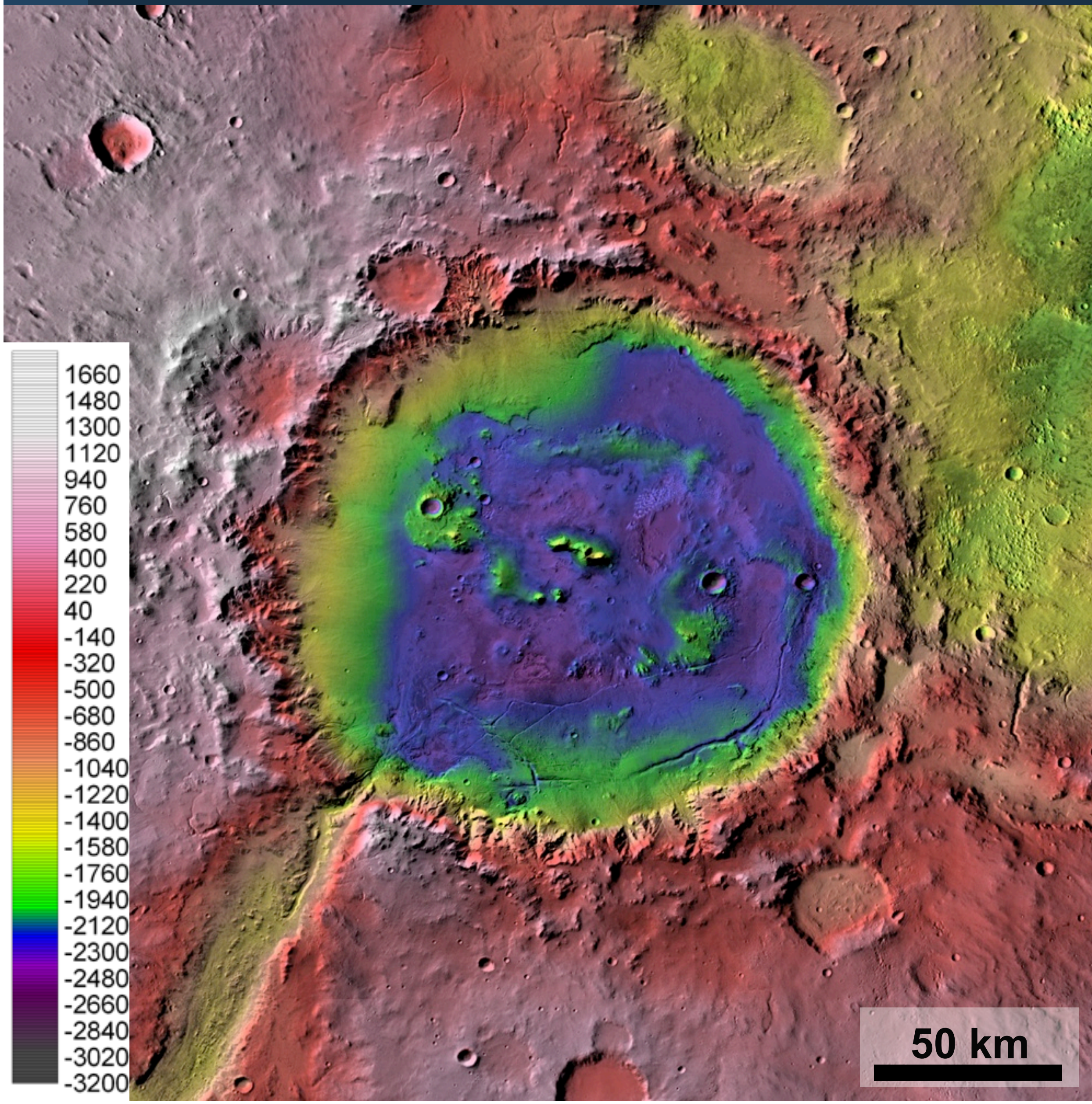
- From width: 455 m^3/s
- From wavelength: 395 m^3/s

Dominant discharge for southern inverted channel

- From width: 142 m^3/s
- From wavelength: 178 m^3/s

- Results are consistent with prior studies (*Moore*, *Jerolmack*, *Irwin*, et al.)
- Southern distributary channel is smaller

Environmental Concepts



Three concepts have been discussed, others or variations of these have been suggested:

- Impact-generated meltwater
- Event to seasonal runoff production
- Runoff production over timescales associated with obliquity cycles

Impact-Generated Runoff

I. Justification

1. Eberswalde watershed lies within continuous ejecta of Holden crater, which contained enough heat to melt ~100 m of ground or surface ice
2. The time between the Holden impact and subsequent erosion is not clear but may be small
3. Some other post-Noachian craters on Mars are similarly dissected
4. Mechanism does not require Hesperian global water cycle, as the global climate remains hyperarid with minor differences from modern Mars

II. Issues

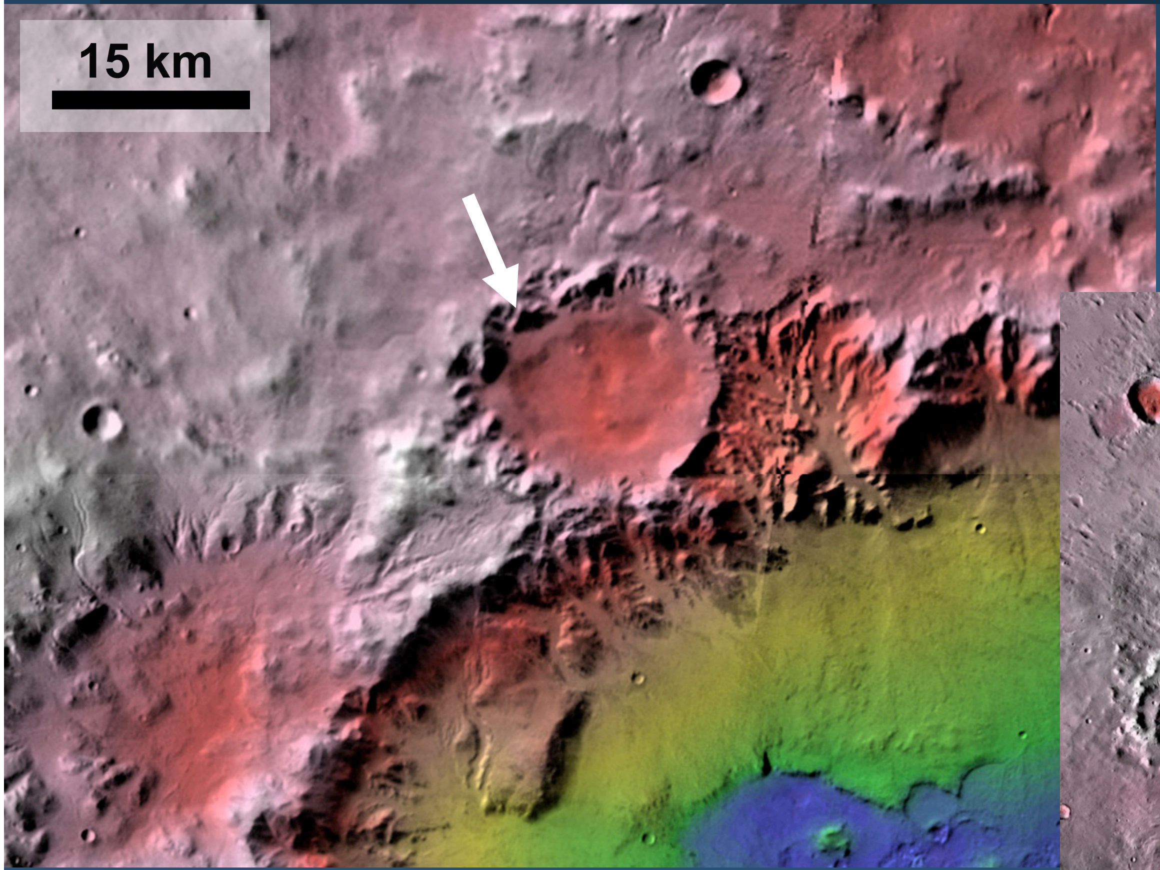
1. Continuous bankfull discharge would require >20 m/yr evaporation from the lake, an order of magnitude more than the energy budget
2. Hesperian valleys formed elsewhere without nearby contemporary craters
3. Precipitation sourced from the crater (lakes) and possibly banked on the rim is implicated for wall erosion & fans; the observation that different sides of nearby craters are heavily dissected has not been explained

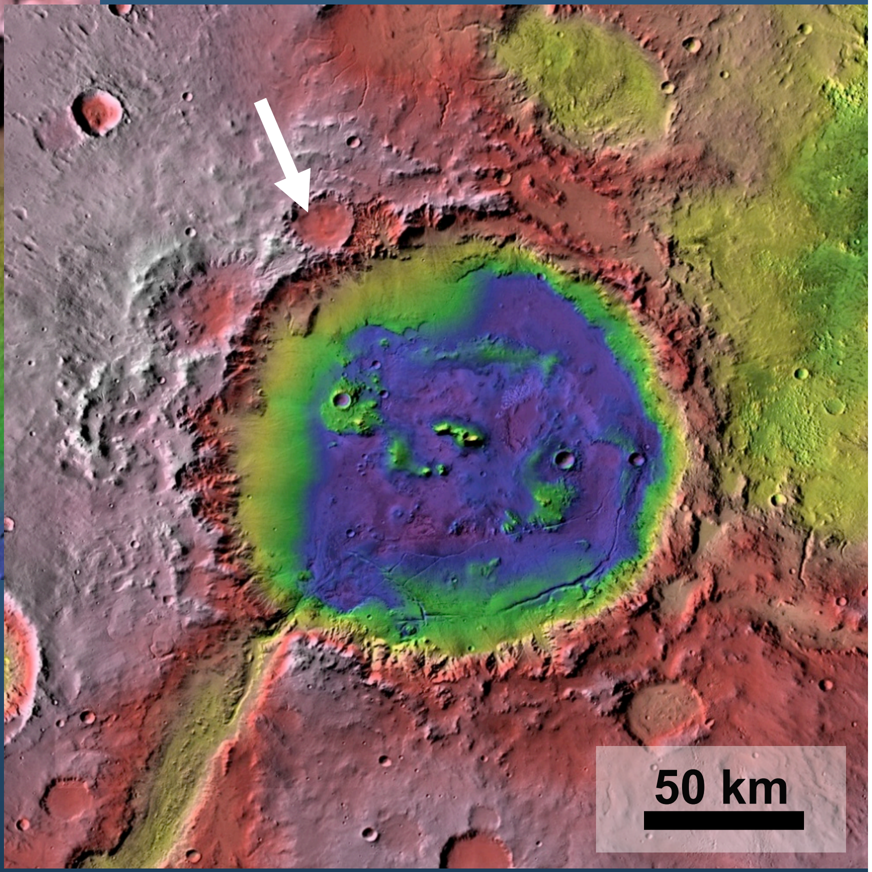
Impact-Generated Runoff

III. Model estimates for Eberswalde (melting pre-existing ice rather than precipitated ice)

1. Runoff production: 9.1 km^3/year or 0.7–1.8 m/yr at 290 m^3/s discharge
2. Duration: ~10^2 year timescale for continuous melting and bankfull discharge
3. Evaporation from 400-km^2 lake: 23 m/year, 1600 W/m^2 to latent heat
4. Solar radiation was <160 W/m^2 averaged over a day, and heat from Holden ejecta beneath the lake could balance evaporative cooling for only ~1 year

Impact-Generated Runoff





This 18-km crater crosscuts Holden rim structures but is degraded. It appears to have formed between the Holden impact and erosion of the wall and rim.

Obliquity Cycles

I. Justification

1. Allows the most time for accumulation of ice, weathering of Holden wall alcoves, and production of sand and gravel for alluvial fans
2. Relies on a recognized Martian volatile cycle

II. Issues

1. Eberswalde delta should be more reworked given inability to maintain the lake level during dry periods; similar melting rates are needed each time to reproduce the lake and avoid fan segmentation (the spillway to the eastern sub-basin helps)
2. Requires melting of surface ice to support the event runoff production rate, but no periglacial reworking of the surface has been identified

III. Model estimates

1. Runoff production and lake evaporation as for seasonal/event scenario
2. Duration: multiple cycles over millions to tens of millions of years

Event to Seasonal Runoff Production

I. Justification

1. Provides a recurring water supply to approximately maintain the lake at the level indicated by the delta (–1400 m), which never became dissected with falling or subsequently rising water level; mass and energy are balanced
2. Precipitation or insolation-driven melting is consistent with the broader distribution of Hesperian valleys or reactivated Noachian ones
3. Limited and likely spatially variable runoff production rates of <1 cm/day are consistent with limited incision of headwater tributaries

II. Issues

1. Requires a widespread atmospheric water cycle of ~10^3–10^4 years total, a rapid decline, and hyperarid conditions before (since the Late Noachian) and after; proposed ways to explain this history are conceptual at best

Event to Seasonal Runoff Production

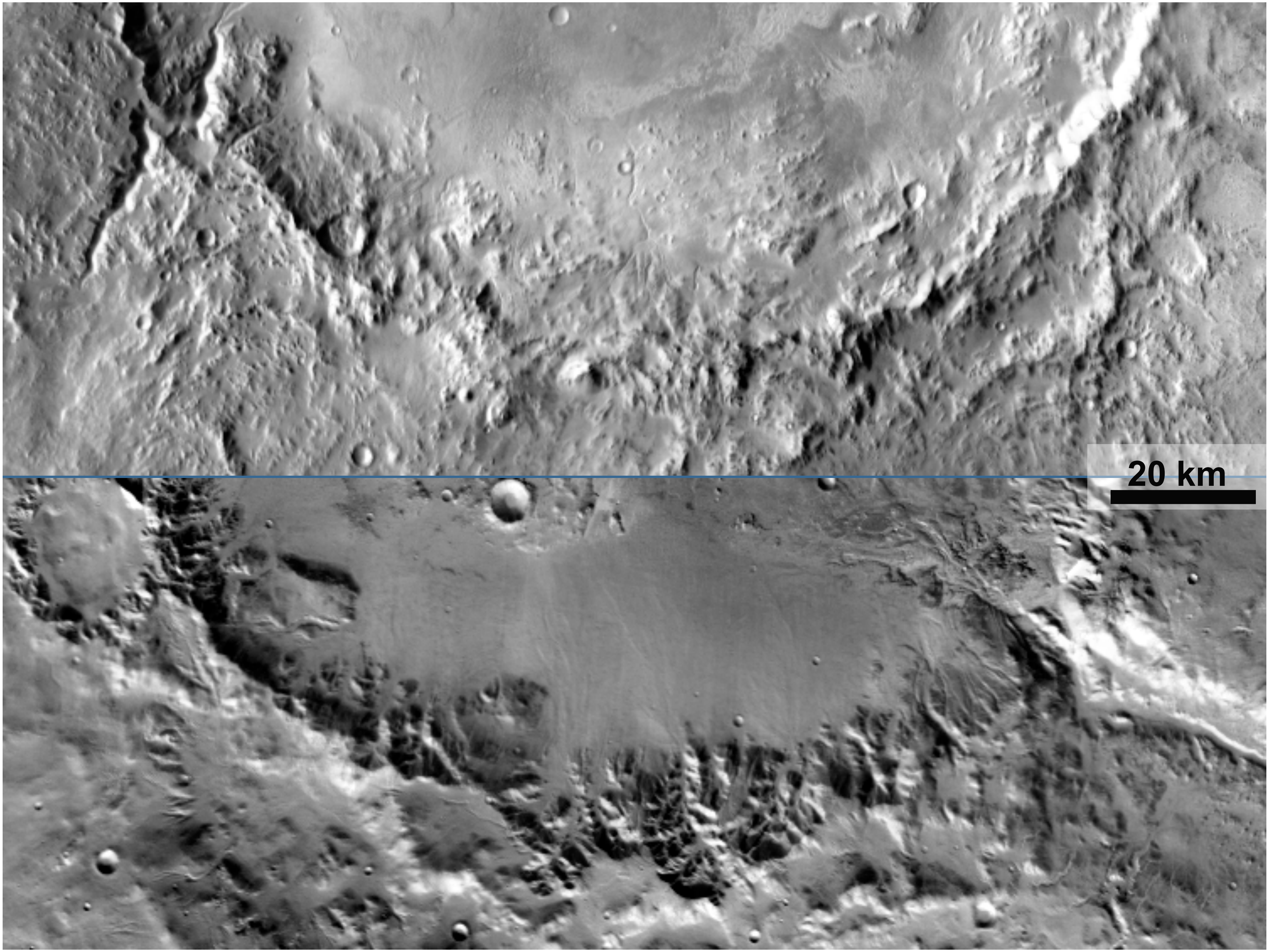
III. Model estimates

1. Runoff production: 0.04–0.4 km^3/year or 0.008–0.08 m/yr, rainfall or snowmelt amounts are higher
2. Duration: ~10^3–10^4 year timescale
3. Evaporation from 400-km^2 lake: 0.1–1 m/year, 7–70 W/m^2 to latent heat
4. Arid climate (cool Nevada?)

Implications of these three basic concepts

Some of the best-developed alluvial landforms do not require humid environmental conditions by terrestrial standards. These concepts range between something like modern Nevada and modern Mars.

Prevailing conditions outside of these erosional epochs were likely drier, even during the Noachian Period, but supportive of slow crater degradation.


20 km

MSL Investigation of Alluvial Deposits

I. Lithology of alluvial sand, gravel, and cobbles

1. Diversity of transported highland material from watersheds

II. Pre-erosional and post-depositional weathering environment

1. Exposure to groundwater in highland crust, chemical energy sources
2. Diagenetic change in highland bedrock before the Holden crater impact
3. Origin of phyllosilicates before or after Holden crater impact
4. Physical and/or chemical weathering of wall rock to produce transportable particles
5. Post-depositional weathering processes on alluvial sediment, contrast with Gusev crater
6. Composition and origin of finer-grained matrix in fan deposits, similar to LTLD?
7. Composition of intermediate-sized component, reworked in aeolian ripples?

MSL Investigation of Alluvial Deposits

III. Fluvial transport processes and environmental implications

1. Matrix- or clast-supported deposits (debris flow or fluvial transport)
2. Grain size, rounding and down-fan changes (flow intensity and transport)
3. Bedding and sorting (more sustained or short, high-intensity flows)
4. Paleosols or duricrusts between beds? (intervals of activity)
5. Post-depositional cementation or loose lag (preservation mechanism)
6. Paleodischarge and runoff estimate from slope, grain size, width
7. If observed, lenticular gravelly deposits at the fan toe could help determine channel width

IV. Sedimentary sequence and relative timing of major stratigraphic units

1. Incision of fluvial flows into LTLD? (change in base level)
2. Interfingering of coarse and fine deposits (test contemporary age of fans and LTLDs)

V. Implications of the above observations for paleoenvironment and habitability

1. Paleoclimate required to yield observed fluvial deposits
2. Atmospheric water supply and changes over time

MSL Investigation of LTL Materials

I. Composition of sedimentary deposits freshly exposed by wind

1. Mineralogy and diversity (advanced weathering products, other sediments)
2. Grain size (energy of depositional setting)
3. Vertical changes in mineralogy and sedimentology (temporal change)
4. Evaporites in or throughout the section? (deep lake or playa?)
5. Cementation, diagenesis, concretions, crystal growth (aqueous activity)

II. Sedimentary structures

1. Bed thickness and sorting, variability thereof (sustained or pulsed supply)
2. Ripples or cross-bedding? (surface or shallow lacustrine flows vs. pelagic)
3. Mudcracks, deflated surfaces, paleosols, duricrusts between beds? (subaerial exposure)
4. Unconformities within the LTL? (major intervals of non-deposition)
5. Other materials in lenses? (contemporary geological activity)

III. Habitability

1. Geochemical environment (inferred pH, dissolved solids and concentration, change or continuity through time: favorability for or effects of biological processes)
2. Preservation, nature, and inventory of organic compounds
3. Inventory the chemical building blocks of life (C, H, N, O, P, S).